Extraction of information and Speckle Noise Reduction in SAR Images Using the Wavelet Transform

Marc Simard[1]
NASA-Jet Propulsion Laboratory
Mail-stop 300-227, 4800 Oak Grove Dr., Pasadena, CA, 91109, USA.
Tel:(818)354-6972 / Fax: (818) 393-5285 / E-mail: simard@bacchus.jpl.nasa.gov

ABSTRACT

This paper presents a method for extracting information from SAR images using the wavelet transform. It is shown experimentally that the shape of the wavelet can be chosen in order to extract different features in the image. Then a new method based on the wavelet transform is used to reduce speckle noise in model SAR image. The result is compared with the more traditional wavelet shrinking method.

INTRODUCTION

The wavelet transform is a mathematical tool widely used in image processing. Some applications of the transform to remote sensing images have been investigated in the literature. It was found useful for texture analysis [1], image compression [2] and noise reduction [3].

The transform allows for representation of a signal onto an orthonormal basis. Each term of the basis represents the signal at a given scale. In order to decompose the signal onto the basis, the algorithm developed by S. Mallat [4] is applied to the signal. It consists of iterations of one-dimensional high-pass and low-pass filtering steps. The algorithm creates a pyramid of low-resolution approximations (at different resolutions) as well as a wavelet pyramid (each pyramid level containing the details of the original image of a given scale). The details are stored as wavelet coefficients. This representation is called a wavelet representation.

An infinity of wavelet bases exist. One way of choosing a particular basis for analysis, is to think in terms of pattern matching. One can choose the wavelet basis which is closest in shape to the feature to be extracted.

It is well known that speckle in SAR images is problematic. Often, it is important to reduce noise before trying to extract scene features. Many filters have been developed to improve image quality by conserving what is thought to be intrinsic scene features and texture. Interpretation of SAR images by human is possible in the presence of speckle. The wavelet transform, as the mammal visual system, provides and allows for a multiscale analysis of images.

This paper presents how the wavelet transform can be used for extraction of linear features such as edges and thin stripes. It will also show how speckle can be reduced by taking into account the speckle contribution to wavelet coefficients.

NOISE CONTRIBUTION

A proportionality relation exists between Speckle noise and the wavelet coefficients [5]. Since Speckle is approached as a multiplicative noise, this contribution will be larger for higher reflectivity regions. It is also known that speckle in SAR images is spatially correlated. That is to say the noise is colored. Therefore its behavior in the Fourier domain is such that there is a peak of a given width around the zero frequency. This is readily observed as a wavelet coefficient variance plateau when decomposing a correlated noise model on a wavelet basis. As decomposition gets to scales larger than the correlation length, the contribution from speckle decreases linearly.

FEATURE EXTRACTION

The wavelet transform is first applied on model images with multiplicative correlated noise (SAR speckle). The noisy models are shown in Fig.1a,b. An asymmetric (or odd-symmetric quadratic splines polynomial) and an even symmetric (cubic splines polynomial) are used to represent the signal (the noisy model). The wavelets are shown in Fig.2a,b.

The speckle contribution is taken into account by normalizing the wavelet coefficients by the local low-pass approximation [6]. The normalization process results in an equal noise contribution for all targets. Unlike the logarithm transform of the SAR images, pixel values are decreased linearly. Fig.3a,b show the wavelet coefficient of the noisy models of Fig.1a,b. The corresponding normalized wavelet coefficients are shown in Fig.4. Visual comparison of Fig.3 and 4 show that the normalization step does not smooth edges or thin linear features. Fig.4 also demonstrates that the asymmetric wavelet performs better at delineating the edges, while the symmetric wavelet perform best to enhance thin linear features. This shows

[1] Marc Simard is a National Research Council Research Associate.

the potential of using different wavelets shapes for feature extraction. The same result can be obtain for 2-D features.

SPECKLE NOISE REDUCTION

Noise reduction using the wavelet transform is in general done by a technique called wavelet shrinking [7]. This technique consists of setting to zero (hard thresholding) the wavelet coefficients which are lower than a given value. The latter being estimated from speckle variance on the first decomposition level. However, this technique lacks in the sense that few building blocks (wavelet coefficients) remain to reconstruct the image. Thus, an artifact will be created in the reconstructed image. The filters used in the wavelet algorithms have a finite spatial extent which is not zero. Therefore the calculated value of a given pixel depends on its neighbors. Setting the neighboring coefficients to zero will therefore modify the value of the analyzed pixel.

The new method consists of locating the wavelet coefficients which are lower than a threshold. These coefficients, meanwhile, will be used for reconstruction of the low-pass approximation within one level of the reconstruction process. The contribution from speckle is removed only after the filtering steps, before the detail images and the low-pass approximation are added for full reconstruction of the higher resolution level. Thus, this process is done for each detail image by setting the pixel values calculated from the high-pass filter to zero.

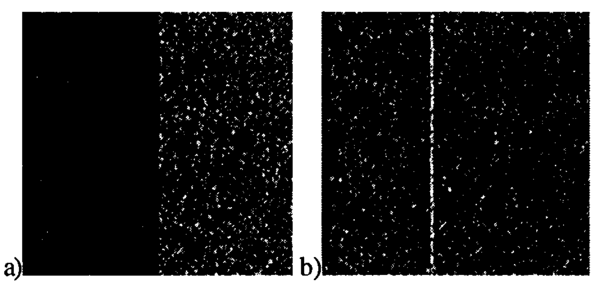


Fig. 1- The model SAR images with spatially correlated speckle noise. An edge model (a) and a thin linear feature (b) are presented, both with a factor of 2 reflectivity contrast.

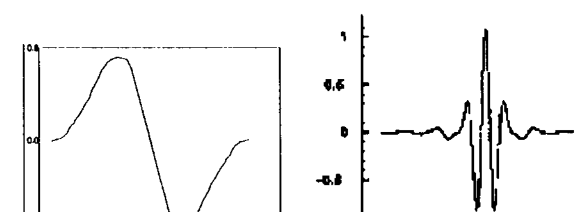


Fig.2 a) The quadratic splines wavelet and b) the cubic splines wavelet studied by Battle-Lemarie.

The choice of threshold is very important and is partly subjective to the level of details needed. The contribution of colored speckle to the wavelet coefficient can be tabulated throughout scale for any type of image. The proportionality relation between speckle and reflectivity must also be considered. In order to take multiplicativity into account, a threshold map is built. The standard deviation values at a given scale are multiplied by the low-pass approximation at the same scale. This can be done because of the orthogonality of the wavelet coefficient and the low-pass approximation. In fact, the low-pass approximations contain the estimated local average reflectivity. The product is the threshold map, which is computed for each scale and orientation. The detail images are then compared to the threshold maps (multiplied by a user chosen factor) to identify the wavelet coefficient that have highest probability to correspond to speckle induced reflectivity variation. The location of those wavelet coefficients is kept in memory, and upsampled detail images are set to zero at that location for pixels in the same orientation as the detail image itself.

The image reconstructed from five decomposition levels is shown on Fig. 5c for 2 standard deviation thresholds. It is compared with the same image reconstructed using wavelet shrinking with 1.5 standard deviations on Fig. 6.

CONCLUSIONS

This short paper has shown the potential of using wavelet transform for feature extraction in SAR images. It is important to note that normalization of the wavelet coefficient by the low-pass approximation does not smooth the detected features.

The new method of speckle noise reduction is fully adaptive, in the sense that it is adaptive to local features by thresholding, and also by being adaptive to the noise level which varies both with reflectivity level and scale.

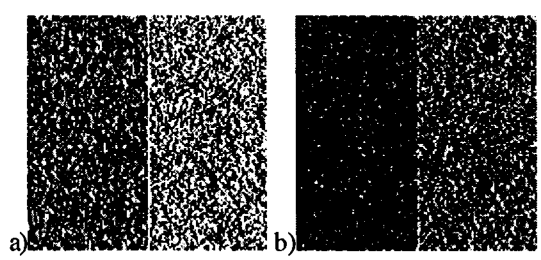
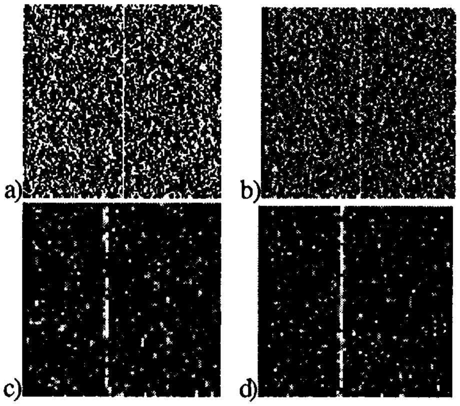
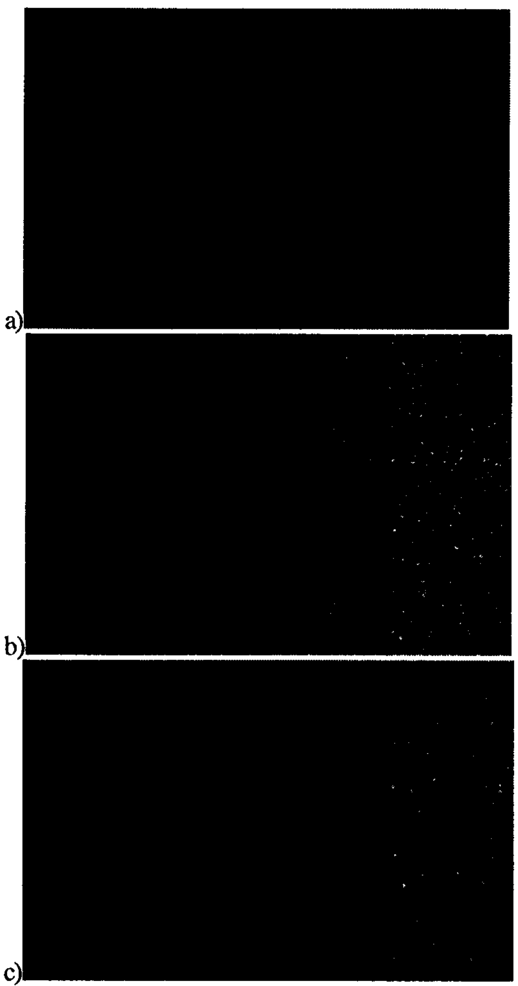


Fig.3- The vertical detail images containing the wavelet coefficients obtained from the image of Fig. 1a. a) was obtained from the asymmetric (or odd-symmetric) quadratic splines wavelet. b) was obtained from the symmetric cubic splines wavelet.



a) b) c) d)

Fig.4- Normalized detail images. Normalization results in equal contribution of speckle for all targets. The main features are well preserved. (a) and (b) are the normalized wavelet detail images from Fig. 1a. (c) and (d) are obtained from Fig. 1b. The symmetric wavelet performs better for thin linear features, while the asymmetric wavelet is best at enhancing the large scale edge.



a) b) c)

d)

Fig.5-a) Model intrinsic reflectivity. b) Noisy model with colored speckle corresponding to a SAR image. c) Reconstructed image using 5 scales with a threshold set to 2 standard deviations with the new method. d) Result using wavelet shrinkage using 5 levels with 1.5 standard deviation.

REFERENCES

[1] T.Chang and J.-C.Kuo, "Texture analysis and classification with tree-structured wavelet transform", IEEE Transactions on image processing, vol.2, no.4, p.39, 1993.

[2] S.Werness, S.Wei and R.Carpinella,"Experiments with wavelets for compression of SAR data", IEEE Transactions on Geoscience and Remote Sensing, vol.32, n0.1, p.197, 1994.

[3] Y.Xu, J.Weaver, D. Healy and J.Lu, "Wavelets transform domain filters: A spatially selective noise filtration technique", IEEE Transactions on image Processing, vol.3, no.6, p.747, 1994.

[4] S.Mallat, "A theory for multi-resolution signal decomposition: The wavelet representation", IEEE Transactions on Pattern Analysis and Machine intelligence, vol.11, no.7, p.674, 1989.

[5] M.Simard, "Analysis of speckle noise contribution on wavelet decomposition of SAR images", IEEE Transaction on Geoscience and Remote Sensing, In Press, 1998.

[6] M.Simard,"Application of the wavelet transform approach: The case of ERS-1 SAR images of the tropical forest", Submitted to the Canadian Journal of Remote Sensing, November 1997.

[7]J. Odegard. H. Guo, C.Burrus and R.W. Jr., "Wavelet based SAR speckle reduction and image compression", SPIE Proceedings, Orlando, 1995.

ACKNOWLEDGMENTS

The author would like to thank Dr. Sassan Saatchi, Dr. Gianfranco DeGrandi and Dr. Keith Thomson for advice and discussions. The author also thanks the NRC Research Associateship program.